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Using Fouggara for Heating and Cooling Buildings in Sahara

S. Amara[(a)*] , B. Nordell[(a)] and B. Benyoucef[(b)], a*

[(a)] *Division of Architecture and Infrastructure Renewable Energy Group*
Luleå University of Technology (LTU), SE-97187 Luleå, SWEDEN
[(b)] *Unité de Recherche Matériaux et Energies Renouvelables (URMER)*
Université de Tlemcen, BP 119 Tlemcen, ALGERIA

Abstract

In order to utilise naturally stored heat or cold from the ground, seasonal temperature variations are required. The reason is that the ground temperature is then warmer than the air temperature during winter and colder during summer. The heating and cooling demand in North Africa varies considerably with the greatest cooling demand in the East and the greatest heating demand in the West. In parts of Algeria the mean temperature difference between the coldest and warmest month is greater than 20°C, which is favourable. In current work it was shown that the ancient Fouggara system, even today would be interesting for heating and cooling of buildings in the Sahara desert.

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Keywords: Energy, Fouggara, heating and cooling, buildings, temperature;

1. Introduction

The development of sustainable buildings partly means to minimize required energy for heating in the winter and cooling in the summer. Increased thermal insulation and air tightness of the envelope reduce heat losses. However, the renewal of air is necessary to maintain good air quality. Air is also used to distribute heating and cooling to the building. Therefore, improving thermal performance of buildings require the control of air exchange.

The ventilation solutions in sustainable buildings provide better control of the air flow, both hygienic and thermal. [1]

* Corresponding author. Tel.: +213-43-21-5890; fax: +213-43-21-5889.
E-mail address: sofiane.amara@ltu.se.

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In this context, we attempt to determine the energy needs for heating and cooling for a building to maintain an indoor temperature between 18°C and 25°C.

The estimated annual fuel consumption, defines required storage volume of fuel or propane gas. For this, several parameters are useful:

- Heat losses from building (kW)
- Number of degree days DD
- Annual distribution of energy consumption
- Uncontrolled losses

The heating and cooling demand of any building also depends on its location. In this study the site is in the Adrar region in Algeria.

Objectives

The objective of current study was to investigate the feasibility of the ancient Fouggara system for heating, cooling and ventilation. The heating cooling demand of a building in Adrar, Algeria, was estimated and the function of the Fouggara was based in real operation data from a Fouggara in the Sahara desert.

2. Geographical characteristics

Adrar is located in south-west of Algeria (Fig.1), 1600 km from Algiers, with latitude of 27.81°, a longitude of -0.18° and an altitude of 279 m. It is characterized very hot and dry summers up to ~50°C and cold winters down to ~0°C (Fig.2a and Fig.2b).

It is difficult to define the building comfort. Thermal comfort is therefore a function of the building is used and the ambient temperature. The width of 'comfort zone' depends on the balance between both parameters.

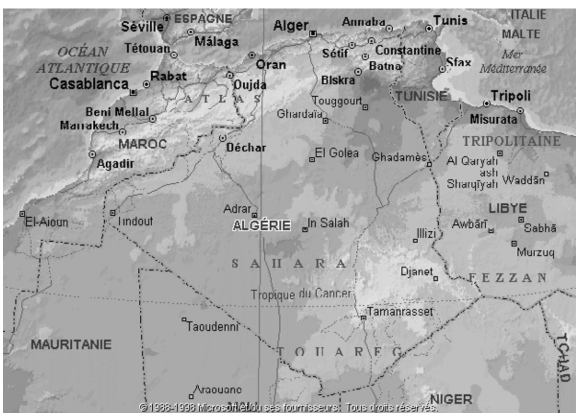

Fig.1: Situation of Adrar site [2]

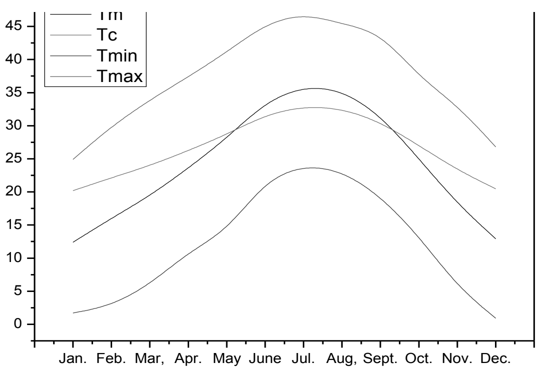

Fig.2 : Monthly temperatures variations

The relationship between comfort temperature and the outdoor temperature is used to design comfortable buildings (Fig.2). Here the indoor comfort temperature (T_c) is calculated from the outdoor temperature mean (T_m) and plotted on a monthly basis together with the monthly mean of the daily maximum (T_{max}), minimum (T_{min}) and mean outdoor temperature (T_m). [3]

Through these results we can see that the Adrar site is characterized by an air temperature ranging from -0.5°C to 47°C. This climate means a long cooling period of 8 months and the 2-3 months heating.

Figure 2 helps the designer to judge whether passive heating and/or cooling is possible. The relationship between the comfort temperature and the range of outdoor temperatures shows whether, for instance, night cooling is likely to be viable in keeping the building comfortable in summer and if passive solar heating will be sufficient in the winter, see Roaf et al, [4]

The heating and cooling demand in northern Africa varies considerably in the different countries. The greatest cooling demand is to the East and in the Sahara desert, while the greatest heating demand is in the North West. In Algeria the heating demand is greater than the cooling demand.

Since the comfort temperature is based on monthly mean air temperature it is not affected by diurnal temperature variations. The indoor temperature variations are fundamental for the occupants comfort since the variations are essential for the energy demand and to maintain comfort.

Based in results presented in Fig.2a and Fig.2b, the heating and cooling DD were calculated, table 1.

Table 1: Monthly degree days variation (DD)

Month	Tc	Ambient average temperatures	DD_h for heating	DD_c for cooling
January	20,2	12.4	-241.8	
February	22,1	16	-172	
March	24	19.4	-142	
April	26,2	23.6	-80	
May	28,7	28.1	-17.8	
June	31,7	33.6		58.7
July	33	36		95
August	33	35.4		86.3
September	30,6	31.6		31.1
October	27	25	-62	
November	23,3	18.2	-153.8	
December	20,5	12.9	-234,5	

Table 1 gives that the Adrar site requires heating during October to May, with the total heating degree days DD_h = 1102. Cooling is needed from June to September based on comfort temperature as the base temperature. The total number of cooling degree days is DD_c = 271.

3. Building

The studied building is part of URER (Renewable Energy Research Unit) in Adrar. A plan drawing of the building is shown in Fig.3. It is seen that the livable surface is of $165m^2$ and the livable volume V_h = 448 m^3. The volumetric heat loss coefficient G, which characterizes the building's thermal quality, considers the thickness of the walls, materials used and the number of openings (Table.2), [5]

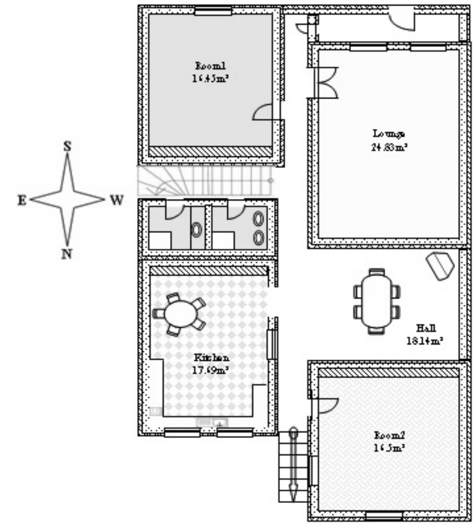

Fig.3: Plan drawing of building

Table 2: Total thermal losses from building

		Walls	Windows	Floor	Roofing	Total losses
Lounge	**K**	3.5	5.8	4	4	
	S (surface)	62.1	6.8	35	35	
	KS	217.3	39.5	140	140	536.4
Hall	**S**	36.4	11.2	20	20	
	KS	127.4	65	80	80	352.4
Room 1	**S**	52	4	25	25	
	KS	182	23.2	100	100	405.2
Room 2	**S**	50.2	5.9	25	25	
	KS	175.7	34.2	100	100	410
Kitchen	**S**	52.9	8.7	30	30	
	KS	185.1	50.5	120	120	475.7
Passageway	**S**	52.4	32	15	15	
	KS	183.4	185.6	60	60	489
Bathroom	**S**	31	4.2	15	15	
	KS	108.5	24.4	60	60	253
TOTAL						2922

Then the total sum of losses (for $\Delta T=1°C$) of the test building is P = 2922 W/°C, see table 2. The volumetric heat loss coefficient G is given by

$$G = \frac{P}{V_h} = 6.52\ (W / m^3 °C)$$

and the volumetric heat loss is then given by

$$C = G \cdot V_h \cdot 24 \cdot DD / 1000 \quad (kWh)$$

The total energy requirements for heating and cooling of the test building are given below.

- Annual requirements for heating for a comfort temperature, October to May :
  DD_h = 1102; where C = 7.7 MWh.

- Annual requirements for cooling for a calculated comfort temperature T_c, June to September:
  DD_c = 271; where C = 1.9 MWh.

4. Heating and cooling by using the ground

Depending on weather, time of day and season, outside air undergoes great variations of temperature and humidity. In contrast, the ground temperature at 10-15 meters below the ground surface is constantly at annual mean air temperature. The air-ground exchanger also called Canadian well or wells Provence - takes advantage of this inertia by contacting the outside air heat with the ground. Its primary purpose is the pre-conditioning of heat and humidity of ventilation air in buildings.

Specifically, the air-ground heat exchanger consists of tubes buried a few meters under the ground, near or directly under the building to ventilate. The air from the outside, moved by a ventilator, runs through the tubes before being blown into the building (Fig.4).

During the passage through the ground tubes, the air flow exchanges heat with the ground and can also deposit some water be condensation into the tubes. The ground-air heat exchanger thus reduces thermal variations and air humidity, which corresponds to pre-conditioned air. This system uses very little driving energy, so, it is almost passive.

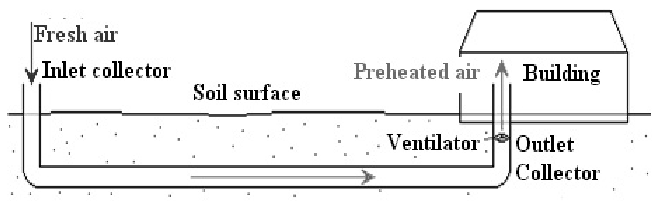

Fig.4: Simplified diagram of a Canadian well-pipe
(Example of operation preheating)

Air-ground exchangers are available on the market. The performance of this type of integrated equipment is benign for sustainable building development.

The Canadian will-pipe system was chosen as the ventilation system of reference for this study. However, several studies address the technology of air-ground heat exchangers, either as a main subject [Mihalakakou et al. 1995[6] et [25]; Benkert et al. 1997[7]; Bojić et al. 1997[8]; Benkert and Heidt 2000[9]; Kunetz and Lefebvre 2001[10]; Hollmuller 2002[11]; Gehlin 2002[12]; De Paepe and Janssens 2003[13]; Dibowski 2003[14], Zweifel 2004[15]; Al Ajmi et al. 2005[16]; Dibowski 2005a[17], 2005b[18]; Ghosal and Tiwari 2006[19]; Badescu 2007[20] and [21], or as a specific study on cooling of buildings.

Such systems are used for cooling of buildings and industrial applications e.g. greenhouses (Gauthier et al. 1997[22]; Hollmuller and Lachal 2001[23], Ghosal and Tiwari op. cit. [19]).

5. Fouggara: An ancient system for underground transport of water

The Fouggara is known under various names; "Kariz" in Afghanistan, "Qanat" in Iran, "Fouggara" in Algeria and "Khettara" in Morocco. The water flow through the Fouggara is gravity driven. At the mouth of the underground channels it reaches the surface where it is used for irrigation and as drinking water, see Fig.5a.

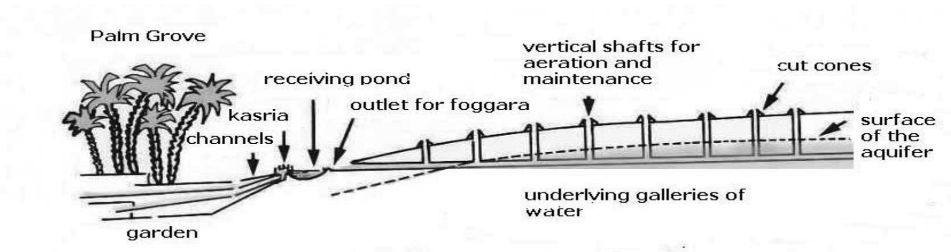

Fig.5a: Outline of the Fouggara principle. [27]

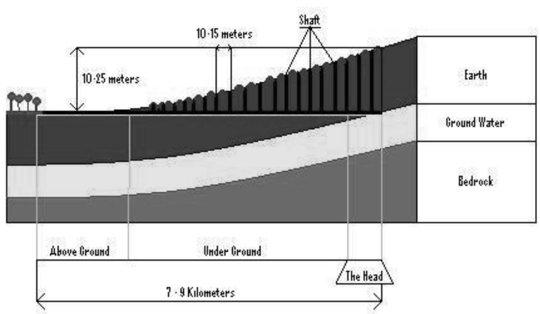

Fig.5b: Vertical section along the Fouggara. [28]

This Fouggara technique is very old and was first used in Iran. It was introduced in Algeria by Arabs at the time of their conquests of Algeria. This technique was adopted by farmers of the area for the following reasons:

- The construction of the Fouggara (Khettara) does not require a financial expenditure, but simply an effort of work.
- Underground transportation of water minimises the water loss due to evaporation and prevents the accumulation of the sediment caused by sandstorms. [26]

5.1. Characteristics

The Fouggara is made up of:

- The source where the water seeps into the channel from a ground water source,
- An underground channel which brings the water to its intended destination,
- An over ground channel which leads to a network of channels feeding the water to particular areas or fields for irrigation.

It is characterised by;

- The length of Fouggara varies from a few hundred meters to tens of kilometres.
- The Fouggara is gravity driven as the water source is situated at a higher elevation then the area to be irrigated.
- The underground channel is wide enough to allow the clearing out and cleaning by hand.
- The depth of the shaft at the source varies from 10 to 25 meters.
- The distance between two consecutive shafts depends in the stability of the terrain and varies between 10 and 15 meters.
- The water flow rate varies from 0.002 to 0.020 m^3/s
- It is located at a depth where the temperature is constantly at annual mean air temperature (i.e. 21^oC in Adrar).

In Algeria the Fouggara is extended over 56000 ha in Naama and in Adrar there are 900 Fouggaras. Today, the land area irrigated by Fouggaras is estimated at 8500 ha though 1/3 of them are in operation. (Fig.6). [24]

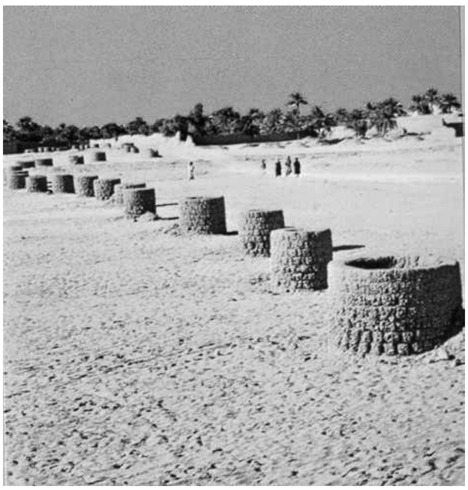

Fig.6: Many wells represent the Fouggara

The existing Fouggaras, active or inactive, means available underground duct systems that could be used as a source for heating and cooling. In the remote Saharan villages of the Saharan people (Fig.7), which lack resources for expensive drilling, available Fouggaras offer an inexpensive alternative. Such a system would be made simply by pumping air through the Fouggara and conducting this air to the air conditioned building. The ambient air then approaches the temperature of the ground (~21°C) during the passage through the ground before used for ventilation, heating, and cooling of buildings (Fig.8).

Fig.7: Fouggara in Adrar.

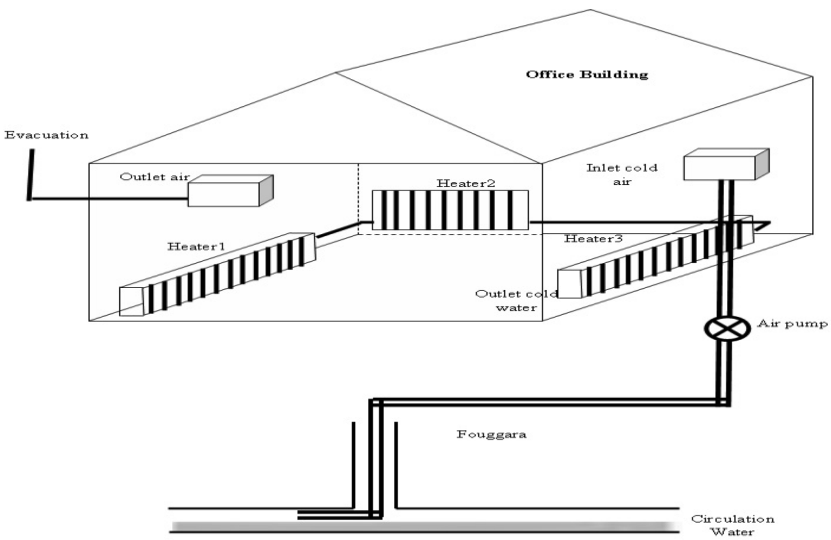

Fig.8 : The ground-air conditioning system. system

The suggested Fouggara air conditioning system, for cooling in the summer and heating in the winter, of the URER test house consists of:

- One room characterized by a volume of 70 m^3
- A pipe system connected to an air convector
- A pump with an air flow rate of 0.02 m^3/h from the Fouggara.

Fig.9 shows the ambient temperature and the air conditioned indoor temperatures during the year, give that the difference between the ambient and indoor temperatures in Adrar is approximately ±20°C.

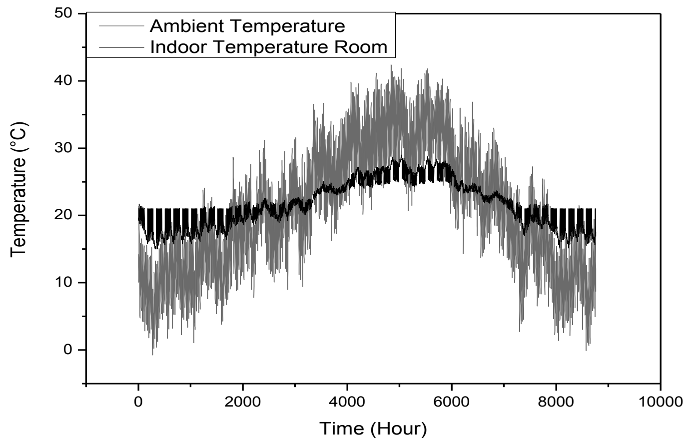

Fig.9: Ambient and Indoor temperature variation

6. Conclusion

The aim was to study the ancient Fouggara system and investigate its possible use as a source for heating, cooling and ventilation of buildings.

The annual energy cooling demand of the test building situated in Adrar gave:

- Heating demand for comfort temperature,
  - October to May: $DD_h = 1102$; where C = 7.7 MWh.
- Cooling demand for comfort temperature,
  - June to September: $DD_c = 271$; where C = 1.9 MWh.

The Fouggara consists of:

- The source where the water seeps into the channel from a ground water source,
- An underground channel which brings the water to its intended destination,
- An over ground channel which leads to a network of channels feeding the water to particular areas or fields for irrigation.

Since the Fouggara is at a depth below ground surface where the seasonal temperature changes do not reach, the Fouggara temperature is close to the annual mean air temperature. In Adrar in the south of Algeria the mean annual temperature is 21°C. Pumping air through the Fouggara means that the air temperature will approach this temperature.

- This novel idea of using an ancient construction as a source for heating, cooling and ventilation has not yet been tested.
- It would be attractive to realize such a test on the test building in Adrar.
- However, before performing such test, simulations of how the operation affects the air and ground temperatures should be made.

References

[1] Thiers, S. (2008). Bilans énergétiques et environnementaux de bâtiments à énergie positive. Thèse de doctorat. Ecole Nationale Supérieure Des Mines De Paris.

[2] Microsoft ® Encarta ® (2008). © 1993-2007 Microsoft Corporation,

[3] Amara, S. (2009). Optimisation des apports d'énergies hybrides dans l'habitat économe. Université Abou Bekr Belkaid Tlemcen.

[4] Roaf. S. C, Fuentes. M, Taylor. S, (2001), The eco-house design guide, London, Architectural Press.

[5] Amara. S, Benmoussat. A, Bouguima. S, Benyoucef. B, Nordell. B, (2007), Requirements energy estimate of heating and cooling for a dwelling in the site of TLEMCEN, ICRESD'07, 21 to 24 May 2007, Tlemcen Algérie.

[6] Mihalakakou, G., Santamouris, M., Asimakopoulos, D. (1995). Modelling the thermal performance of earth-to-air heat exchangers, Solar energy. Vol 53 (3). pp. 301–305.

[7] Benkert, S., Heidt, F. D., Schöler, D. (1997). Calculation tool for earth heat exchangers GAEA, Proceedings of IBPSA Conference. Prague.

[8] Bojić, M., Trifunović, N., Papadakis, G., Kyritsis, S. (1997). Numerical simulation, technical and economic evaluation of air-to-earth heat exchanger coupled to a building, Energy. Vol. 22 (12). pp. 1151–1158

[9] Benkert, S., Heidt, F. D. (2000). Abschlussbericht zum Projekt : Validierung des Programms "Graphische Auslegung von ErdwärmeAustauschern GAEA" mit Hilfe von Messdaten im Rahmen des Verbundprojekts "Luft-/Erdwärme tauscher" der AG Solar NRW. FG Bauphysik & Solarenergie, Universität Siegen, 89 p. Disponbile en ligne.
URL : http://nesa1.uni-siegen.de/softlab/download/abschlussbericht.PDF

[10] Kunetz, J., Lefebvre, L. (2001). Les puits provençaux. Etude et méthode de dimensionnement. Rapport de projet tutoré de 5ème année. INSA de Toulouse. Janvier 2004. 54 p

[11] Hollmuller, P. (2002). Utilisation des échangeurs air-sol pour le chauffage et le rafraîchissement des bâtiments. Thèse de doctorat. Faculté des sciences de l'Université de Genève. 125 p. Disponible en ligne. URL : http://www.unige.ch/cyberdocuments/theses2002/HollmullerP/these.html

[12] Gehlin, S.: Thermal response test – Method development and evaluation. Doctoral Thesis 2002:39, LuTH, 2002.

[13] De Paepe, M., Janssens, A. (2003). Thermo-hydraulic design of earth-air heat exchangers, Energy and Buildings. Vol. 35 (4). pp. 389–397.

[14] Dibowski, H. G. (2003). Auf Basis umfangreicher Messdatensätze experimentell und numerisch validierte Regeln zur optimierten Auslegung von Luft-Erdwärmetauschern. Thèse de doctorat. Universität Kassel. Kassel. 225 p.

[15] Zweifel, G. (2004). A simplified model of a Ground to Air Heat Exchanger. Hochschule für Technik+Architektur Luzern (HTA Luzern). Horw. 6 p.

[16] Al Ajmi, F., Loveday, D.L., Hanby, V.I. (2005). The cooling potential of earth-air heat exchangers for domestic buildings in a desert climate, Building and Environment. Vol. 41 (3). pp. 235–244.

[17] Dibowski, H. G. (2005). Luft-Erdwärmetauscher L-EWT Planungsleitfaden Teil 2: Testanlagen im Verbundprojekt. Rapport AG Solar. Köln. 102 p.

[18] Dibowski, H. G. (2005). Luft-Erdwärmetauscher L-EWT Planungsleitfaden Teil 2: Technishe Planung. Rapport AG Solar. Köln. 62 p.

[19] Ghosal, M. D., Tiwari, G. N. (2006). Modeling and parametric studies for thermal performance of an earth to air heat exchanger integrated with a greenhouse, Energy conversion and management. Vol. 47 (13-14). pp. 1779-1798.

[20] Badescu, V. (2007). Simple and accurate model for the ground heat exchanger of a passive house, Renewable energy. Vol 32 (5). pp. 845–855.

[21] Badescu, V., Sicre, B. (2003). Renewable energy for passive house heating: II. Model, Energy and Buildings. Vol. 35 (11). pp. 1085–1096.

[22] Gauthier, C., Lacroix, M., Bernier, H. (1997). Numerical simulation of soil heat exchangerstorage systems for greenhouses, Solar energy. Vol. 60 (6). pp. 333–346.

[23] Hollmuller, P., Lachal, B. (2001). Cooling and preheating with buried pipe systems: monitoring, simulation and economic aspects, Energy and Buildings. Vol. 33 (5). pp. 509–518

[24] Bouzidi, B. (1999). L'Energie Solaire et les Régions Sahariennes : Exemple de la Région d'Adrar. Revue des Energies Renouvelables : Valorisation. pp101-104.

[25] Mihalakakou, G., Santamouris, M., Asimakopoulos, D.N., Argiriou, A. (1995) On the ground temperature below buildings, Solar energy. Vol. 55 (5). pp. 355–362.

[26] El Faiz, M., Ruf, T. What stakes of development for the systems of khettara (Water mines) in Morocco. Disponible en ligne:
www.isiimm.agropolis.org/OSIRIS/article/maElFaizRuf2006_khettaras2.pdf El Faiz, M., Ruf, T. What stakes of development for the systems of khettara (Water mines) in Morocco.

[27] Khettara : http://jorf.sagya.org/english/thekhettara.htm

[28]Khettara : www.jorf.sagya.org/photos/khettara.